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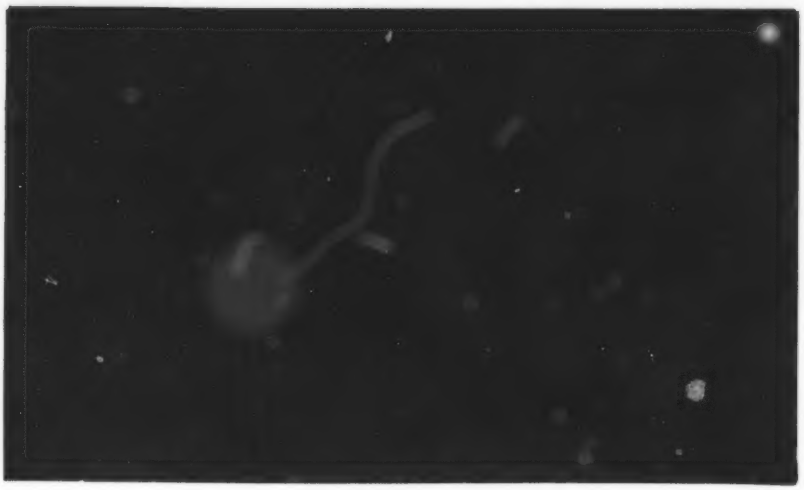

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STRATEGIC PLANNING OF FREIGHT TRANSPORTATION IN BRAZIL: METHODOLOGY AND APPLICATIONS

Part 1
PROJECT SUMMARY

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ABSTRACT

This is the final report of the cooperative project *Strategic Planning of Freight Transportation in Brazil*, carried out jointly by the Centre de Recherche sur les Transports of the Université de Montréal, the Pontifícia Universidade Católica do Rio de Janeiro and GEIPOT, the National Transportation Planning Company of the Brazilian Ministry of Transportation, with the financial support of the International Development Research Centre (Canada). The report consists of five parts:

Part I	Project Summary
Part II	Methodology: The New Contributions
Part III	The STAN System
Part IV	Specifying Data for the STAN System: Requirements, Concepts, Sources and Estimation Procedures
Part V	Applications.

Part I is a project summary that states the main objectives of the project, reviews the history of the project and summarizes the achievements made in the new methodological contributions, the development of the STAN system, the specification of data for use with the STAN system, the applications carried out, as well as a conclusion on the entire project.

KEY WORDS: Multimode Multiproduct Freight Transportation,
Network Optimization Models,
National/Regional Strategic Analysis and Planning of Freight Flows,
Interactive-Graphic System.

RESUME

Ceci est le rapport final du projet de coopération *Strategic Planning of Freight Transportation in Brazil*, réalisé conjointement par le Centre de recherche sur les transports de l'Université de Montréal, la Pontifícia Universidade Católica do Rio de Janeiro et GEIPOT, l'agence de planification nationale du ministère des transports du Brésil, avec le support financier du Centre de recherches pour le développement international (Canada). Le rapport a cinq parties:

Part I	Project Summary
Part II	Methodology: The New Contributions
Part III	The STAN System
Part IV	Specifying Data for the STAN System: Requirements, Concepts, Sources and Estimation Procedures
Part V	Applications.

La partie I est un sommaire du projet qui décrit les objectifs du projet, en donne un bref historique et résume les contributions méthodologiques, le dévelopement du système STAN, la spécification des données pour l'utilisation du système STAN, les applications accomplies ainsi, qu'une conclusion générale du projet.

MOTS CLES: Transport multimode multiproduit de marchandises,
Modèles d'optimisation de réseaux,
Planification stratégique nationale/régionale,
Système interactif-graphique.

PART 1

PROJECT SUMMARY

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CHAPTER ONE

HISTORY OF THE PROJECT

1.1 THE BEGINNING

The initial impetus for the initiation of this project resulted from exchanges between Professors Luiz A.F.M. Gomes and Cristine Ann Assis of the Department of Industrial Engineering of the Pontificia Universidade Católica of Rio de Janeiro (PUC-RJ) and Professor Michael Florian of the Centre de recherche sur les transports of the Université de Montréal (CRT-UdeM) in 1981.

At that time Brazil had already accumulated a sizable external debt and the export of Brazilian goods in increasing amounts was required in order to earn foreign currency. The late 1970's and early 1980's was also the period of high prices for imported crude oil; a significant proportion of these imports were consumed in the transportation sector, which was used for shipping the exported goods from inland origins to export destinations. Hence, the need for a strategic planning method, that could be used at the level of the entire country and would permit the evaluation of lower energy consuming transportation options, led to the proposal of a project intitled *Energy Consumption and Freight Transportation in Brazil: Development of Strategic Framework for Policy Evaluation.* This project was submitted by the PUC-RJ to CNPq (The Brazilian National Research Center) and was strongly supported by its then President, Dr. Lynaldo Cavalcante de Albequerque. During 1981, Professors Michael Florian and Luiz A.F.M. Gomes met with Mr. Ernest Corea, Director, Cooperative Programs Unit of IDRC, to solicit support for a cooperative project on this theme. After a period of evaluation, IDRC, represented now by Mrs. Rachel Des Rosiers, Assistant Director, Cooperative Programs, judged that the project had a

chance to succeed only if the Brazilian Ministry of Transportation would support the project by providing the necessary data and eventually implement the results of the project. In September 1982, Professor Michael Florian and Dr. Sitoo Mukerji, who had been assigned by IDRC as project coordinator, visited Brazil and held meetings in Rio de Janeiro at PUC-RJ and in Brazília with the staff of GEIPOT, the transportation planning company of the Ministry of Transportation of Brazil. It was of great significance that Dr. Francisco de Paula Magalhães Gomes, Director of GEIPOT, supported the project by agreeing to provide immediately the available data and in October 1982, we received a strong letter of support from Dr. Jose Menezes Senna, President of GEIPOT. The collaborative project intitled by then *Strategic Planning of Freight Transportation in Brazil* was formally approved by IDRC in February 1983.

1.2 THE MAIN OBJECTIVES OF THE PROJECT

It is appropriate here to mention the general aims of the project in more detail. The principal aim of this collaborative project between PUC-RJ, CRT-UdeM and GEIPOT was to develop the means and the methods for evaluating contemplated changes in the transportation infrastructure that is used for freight movements in Brazil, with a particular emphasis on energy consumption. The planning methods envisaged and the data base that supports these methods were to be implemented in Brazil and provide the capability for carrying out strategic planning exercises on a continuing basis.

The strategic level of planning implies a medium to long term horizon and a rather aggregate level of detail for the representation of the transport services provided. The contemplated alternatives represent usually anticipated (or predicted) changes in the

origin to destination demands for the commodities considered and major changes in the transporattion infrastructure. At the strategic level of planning, the aim is to obtain an overall evaluation of the movement of freight of most (or all) commodities on most (or all) of the modes available; thus tactical decisions (such as when to schedule the trains that are operated) are not considered at this level.

We identified the need to develop methods that would be used to simulate flows, service levels, costs and fuel consumption for a given alternative by taking as input the origin to destination demands, the allocation of products to particular modes, the transportation infrastructure with link capacities, transshipment terminals with their delay and cost characteristics, and predict the way in which the demands give rise to the link flows for each mode and to transshipment flows through terminals.

The service levels, cost and fuel consumption from origins to destinations are derived from link and terminal delays by an appropriate methodology for each mode. Such a method would be implemented for easy use by making it available in an interactive-graphic computing environment and would be supported by a suitable data base.

In order to achieve this aim, the projet was subdivided among the three institutions to best suit their competence: PUC-RJ took on the task of analysing and describing the Brazilian context of freight transportation, analysing the origin/destination matrices and contributing to the modeling of the rail mode; CRT-UdeM took on the task of developing the methodology required to meet the aims of the project and the computer based implementation of the method; GEIPOT took on the task of providing the required data, provide policy guidance to the project and eventually implement the resulting method towards the end of the project. Clearly, the division of the project tasks was not completely disjoint, as members of each

team collaborated on aspects of the project which were of mutual interest and common competence.

1.3 THE FIRST THREE YEARS

The project started in earnest with the visit of Professor Luiz A.F.M. Gomes to Montréal in March 1983 and then with a visit of Professor Michael Florian to Brazil in June of 1983. During that visit, the project plan, that was submitted in the proposal to IDRC, was first put into action and new contacts were established with Dr. Vande Lage Magalhães, the new Director of GEIPOT and Dr. Wande Pereira Borges, the new President of GEIPOT.

During the meetings held at GEIPOT during June 1983, it was agreed that the development work could not be done without reference to a particular region of Brazil. As a consequence, GEIPOT's suggestion, of carrying out the research and development work with reference to the South-East region of Brazil, consisting of the States of São Paulo, Rio de Janeiro, Minas Gerais and Espiríto Santo, which represents about 70% of the Brazilian economic activity, was considered by the project team. The other possibility was to carry out the initial work with reference to the South region of Brazil. During the month of August 1983, Professor Jean-Marc Rousseau, Dr. Teodor Gabriel Crainic and Professor Luiz A.F.M. Gomes visited the major transportation facilities in the South and South-East regions of Brazil. This intensive visit was arranged graciously by Dr. Vande Lage Magalhães, Director of GEIPOT. Following this visit, which provided a better understanding of the freight transportation in Brazil and the particular characteristics of each region, as well as a review of the data sources available and the priorities of GEIPOT, it was decided that the South-East region of Brazil will serve as the pilot region for the study. We received

excellent cooperation and assistance from Economist Raimundo Caramuru Barros of GEIPOT. It is also appropriate to mention the good guidance that we received during the initial stage of the project from Dr. Sitoo Mukerji, who coordinated the project for IDRC.

During the first year of the project, most of the data analysis and research work was carried out at PUC-RJ and CRT-UdeM. It involved professors, researchers and students at both university.

At the beginning of the second year of the project, Professor Michael Florian, Dr. Teodor Gabriel Crainic and Professor Jean-Marc Rousseau undertook a trip to Brazil to hold meetings at GEIPOT and PUC-RJ. The visit had as one of its main aims to define more concretely the way in which GEIPOT would participate in the project and the planning problems that GEIPOT expects to be able to address with the help of the methods being developed in the project. A first series of meeting were held in Brazília, with the participation of Professor Luiz Roberto F. Costa, who had become project coordinator for PUC-RJ, as well as Professors Oswaldo Lima Neto and Nélio D. Pizzolato of PUC-RJ. These meetings resulted in the identification of the planning issues of relevance to Brazil and GEIPOT. The president of GEIPOT expressed his support for the project and confirmed the active participation of his organization in the project. The subsequent meeting at PUC-RJ served to establish the way in which the participating Brazilian organizations, PUC-RJ and GEIPOT, would coordinate their activities with those at the CRT-UdeM. Throughout these meetings, discussions were held on various technical issues related to the research carried out in the project.

The direct consequence of this meeting was the appointment in July 1984, of Mr. Luiz Francesco Modenese Vieira to be the GEIPOT coordinator of the study and the assignment of GEIPOT staff to the project. In August 1984, a Technical Cooperation

Agreement between the Université de Montréal, GEIPOT and PUC-RJ was signed, to reinforce formally the collaboration of the three institutions in the project. At about the same time, Mr. Robert Rowe replaced Dr. Sitoo Mukerji as project coordinator for IDRC.

The work on the project was continued during the summer of 1984 and in September 1984, Professor Michael Florian, Dr. Teodor Gabriel Crainic and Professor Sang Nguyen visited PUC-RJ to review the progress in the project and visited Brazília to meet the new president of GEIPOT, Mr. Marcelo Berubato de Silva and the team working at GEIPOT. An important meeting was held on the occasion of this visit with representatives of FEPASA, the railway company of the state of São Paulo, RFFSA, the Brazilian national railway company and CVRD, a private company that mines and exports iron ore and operates a very efficient rail company to transport the iron ore. This meeting served to inform these companies of the project and the role that GEIPOT could assume in the application of strategic planning methodology.

The methodological aspects of the project began to crystalize towards the end of 1984 and the beginning of 1985. In March 1985, Professor José Eugenio Leal spent a productive visit in Montréal that was dedicated to the analysis and quantification of costs for the rail mode in Brazil.

A critical phase of the project occured in May 1985. The Director of GEIPOT, Dr. Vande Lage Magalhães, had already expressed the need to have access to computer hardware that would allow GEIPOT to use the interactive graphic planning method that was being developed during the project. This issue was addressed during a meeting held in Brazília with GEIPOT, PUC-RJ, CRT-UdeM staff and Mr. Robert Rowe of IDRC. The conclusion reached regarding the most cost-effective solution to this question was to equip GEIPOT with two workstations based on IBM PC/AT

microcomputers with Definicon DSI-32 co-processor boards and two high resolution graphic terminals. The purchase of this equipment would be financed by IDRC.

On the occasion of that visit, an intensive working session of 10 days was held at PUC-RJ, with participation of Mr. Luiz Francesco Modenese Vieira as well.

The next working meeting was held in Montréal in August 1985 with the participation of Professor José Eugenio Leal and Mr. Luiz Francesco Modenese Vieira. By that time, it became evident that another year would be required in the project for the full implementation of the strategic planning method developed during the project. Dr. Oswaldo Lima Neto, who had left PUC-RJ to become Director of GEIPOT, indicated that GEIPOT would allocate more resources to the project during the implementation phase and a joint proposal of the three participating organizations was submitted to IDRC. This proposal was approved and the Implementation Phase began in March 1986.

The main result of the project, the STAN (**S**trategic **T**ransportation **AN**alysis) interactive-graphic system for strategic transportation analysis at the national level, come to fruition at the end of the third year of the project. It was installed in Brazília on the equipment donated to GEIPOT by IDRC and at PUC-RJ at the beginning of August 1986, during a two week visit, which was undertaken by Professor Michael Florian, Dr. Teodor Gabriel Crainic, Mr. André Babin and Mr. Jacques Guélat. A first course on the use of STAN was given in Brazília and was attended by GEIPOT staff and Professors José Eugenio Leal and Walter Porto of PUC-RJ. At the end of the visit, a presentation was made to the Board of Directors of GEIPOT on the accomplishments of the project and the STAN system. It should be mentioned that there had been another change in the GEIPOT upper management. The new President of GEIPOT was Dr. Stanley Forte Batista and Mr. Wellington Figueiredo was Director of GEIPOT in charge of coordinating the project.

1.4 THE IMPLEMENTATION PHASE

The implementation phase of the project began in earnest after the installation of the equipment and software at GEIPOT. Another visit, undertaken by Professor Florian and Mr. Jacques Guélat in December of 1986 to visit PUC-RJ and GEIPOT served the purpose of holding several seminars on the methodology developed and in the use of the STAN system. The preparation of the data required for a full application of the model revealed that, due to the interest expressed by the regional offices of GEIPOT, several pilot applications would be carried out. Also, GEIPOT staff expressed their preference for carrying out a full application of the STAN system on the Corridor of the São Francisco River, one of the strategic corridors of Brazil, where a study of the possibility of an increased utilization of the river São Francisco was scheduled to take place. STAN will be used to perform analyses of various strategic development scenarios. This was an appropriate choice, since the data base for the South-East region of Brazil, which was used during the first three years of the study, was not entirely ready. Both GEIPOT and PUC-RJ had yet to complete some parts of the data base, which were difficult to carry out in time for a comprehensive application. It was also evident that, due to its size, the São Francisco corridor was much better suited for a first application than the South-East region. A larger application could be performed later on, after the implementation phase of the project would have been completed.

A last visit during the implementation phase was undertaken by Dr. Teodor Gabriel Crainic and Mr. Jacques Guélat at the end of March 1987. A new and updated version of the STAN software was installed both at GEIPOT and PUC-RJ. As GEIPOT had undergone an internal reorganization, the direct responsibility for the project was assigned to the research and development manager, Mr. Theodoro Cavalho Lustosa. The Director of GEIPOT responsible for the project was still Dr.

Wellington Figueiredo. This meeting also served to plan the preparation of the final report and an eventual final seminar that would summarize the achievements of the project.

The implementation phase of the project concluded with the transmittal of reports prepared by GEIPOT and PUC-RJ on the aspects of the project that each institution had carried out. The contents of these reports have been integrated in the other chapters of this report.

CHAPTER TWO

THE PARTICIPANTS

This project could never have been undertaken without the support of IDRC. This support was not only financial, as both project officers that have been assigned to coordinate our project, Dr. Sitoo Mukerji and Mr. Robert Rowe, provided general policy guidance for the project and contributed actively to the deliberations between the three participating organizations. Mrs. Rachel Des Rosiers, Assistant Director, Cooperative Programs, at IDRC, overlooked the development of the project and intervened in critical and delicate decisions with patience, wisdom and tact.

The PUC-RJ team was composed of several professors and researchers from the departement of Industrial Engineering. Professors Luiz A.F.M. Gomes, Cristine Ann Assis, Nélio D. Pizzolato, Thadeo Keller Filho, Walter Porto jr., José Eugenio Leal, Oswaldo Lima Neto and Luiz Roberto F. Costa contributed to the project in its various stages. They were asssisted by researchers Cláudio Amarente de Almeida Magalhães, Maria Luiza Villares and several other research assistants. Professors Luiz A.F.M. Gomes, Luiz Roberto F. Costa and Walter Porto jr. acted successively as project coordinators for the PUC-RJ team.

The GEIPOT team, headed by Mr. Luiz Francesco Modenese Vieira, included Ms. Maria Izabel David and Ms. Maria Cleia Martins. In addition, Mr. Noboru Ofuji participated in the project during the implementation phase. Throughout the meetings held at GEIPOT, Economist Raimundo Caramuru Barros assisted the project team in obtaining data and acces to members of GEIPOT staff who provided insight into questions that concerned all aspects of the Brazilian transportation system. Mr. Ernesto de Campos Sigiliano and then Mr. Theodoro Cavalho Lustosa provided the

management of the GEIPOT team during the project.

It is also important to mention that during the carrying out of the project, numerous other professionals in the employ of GEIPOT participated in various meetings, providing information, opinions, views and advice. It is worthwhile to mention the assistance of Mrs. Maria das Graças Rolim Bilich, Mr. Lycurgo do Rego Borros Alemeida and Dr. Kim Kwei Yin.

Last but not least, the continued support of the Presidents and Directors of GEIPOT, mentioned in the history of the project, was invaluable to the GEIPOT team in particular and to the entire project team in general.

The CRT-UdeM team consisted of Professor Michael Florian, project coordinator, Dr. Teodor Gabriel Crainic, who acted as the Secretary of the project, Professors Sang Nguyen and Jean-Marc Rousseau. They were assisted by Miss Marie-Claude Roy, Miss Nathalie Rico and Mr. Louis Senecal, who completed their M.Sc. theses on methodological topics considered in the project. The programming of the STAN system was carried out by Mr. André Babin and Mr. Jacques Guélat, analyst-programmers employed by the CRT. In particular, Mr. Guélat made significant methodological contributions as well. Professor Jean-Marc Rousseau, who was Director of the CRT-UdeM during the execution of the project, provided strong support and encouragement for the succesful completion of the project.

CHAPTER THREE

THE ACHIEVEMENTS

3.1 INTRODUCTION

In a collaborative project, where the participating institutions are separated geographically, two being in Brazil and one in Canada, as well as being very different in their organizational structure, one being a governmental company and the other two universities, the completion of the project is an achievement in itself. However, the results of the project are most satisfying and comprise new contributions to methodology, the development and implementation of the STAN system, the preparation of data for the strategic planning process and the applications carried out in Brazil with the STAN system.

3.2 METHODOLOGY: THE NEW CONTRIBUTIONS

The main challenge facing the project team was to provide general modeling concepts and methods for simulating freight flows for a national multimode multiproduct transportation system. These general concepts and methods should be suitable for strategic transportation planning and yet efficient, from a computational view point, in order to be integrated in a user friendly interactive-graphic computational environment.

The new methodological contributions consist in the way that a national freight transportation system is represented for strategic planning purposes, the way in which the various modes are represented and a multimode multiproduct network assignment

model that simulates the freight flows on any given network scenario.

The class of models that we have developed during the project do not consider shippers and carriers as distinct actors in the decisions made in shipping freight. The level of aggregation which is appropriate for strategic planning of freight flows, where origins and destinations correspond to relatively large geographical areas, leads to the specification of supplies and demands, for all the products considered, which represent the services provided by all the individual shippers for the same product. In Brazil, demand for strategic freight analyses were determined from data sources (national freight flow analyses, input/output analyses) which permit to identify the mode used, but do not contain information about individual shippers. However, the demand data that was available and the demand forecasts made reflect the behavior of the shippers. Nevertheless, the models that we have developed consider the competition among the modes of transport, whenever it is present.

The assumption is made that goods are shipped at least total generalized cost, which includes delay, operating cost and fuel consumption. At a strategic level of planning freight flows, where major quantities of bulk products are transported and the scenarios considered are associated with investments of large magnitude, this assumption is justified, even though the shipment of freight is governed by a variety of micro-circumstances which prevent the actual achievement of total cost minimization. The normative approach is particularly appropriate when certain products are captive to a mode, or a subset of modes, due to service availability or regulation, which is often the case in Brazil.

The multimodal aspects of the national transportation system are accounted for in the network representation chosen. A link of the multimodal network is defined by its origin and destination nodes and a single mode. Parallel links are allowed

between two adjacent nodes, one for each mode available to transport goods between them. The intermodal transfers at a node of the network are modeled as link to link permitted movements. Appropriate cost functions are associated with links and intermodal transfers.

The multiproduct aspects of a national transportation system are accounted for in the formulation of the predictive model and is exploited in the solution procedure. The algorithm developed for this problem exploits the natural decomposition by product and results in a Gauss-Seidel like algorithmic procedure.

Demand and mode choice are exogenous and are assumed to specify, for each product, a set of origin/destination matrices, each of which may only use a subnetwork that corresponds to a permitted subset of modes. The choice of the paths used through a permitted subnetwork is determined by the particular form of the generalized cost functions, which also take into account the congestion conditions.

The multimode multiproduct model was formulated and a solution algorithm, which uses a decomposition by product, was developed. This model and the solution algorithm were imbedded in the STAN interactive-graphic system, which is one of the main results of the project. A complete description of these developments is given in Part 2, Chapter III of this report.

Rail is an important part of any national transportation study. Consequently, a significant amount of modeling effort was dedicated to an adequate representation of the rail mode and its interaction with the other components of the transportation system. In Brazil, transport of goods by rail is regulated. It is also an energy efficient mode and it is considered in a developing country, such as Brazil, as an important economic means to open up new regions to population and economic development, to bring products for export from the producing regions to ports and to transport

imported goods to the consumption centers of the country.

In the project, we developed a way to model the rail freight transportation system, its components and operations, that is compatible with the strategic objectives of the planning system and the representation of the other transportation modes that compose a national multimode transportation system. The contributions made in the modeling of the rail mode include a detailed description of the rail network model, that is coherent with the general modeling concepts adopted, the formulation of cost and delay functions that have as an input the number of tons transported, as well as a discussion of the empty car distribution planning in the context of strategic planning. This is the subject of Part 2, Chapter IV of the report.

A multimodal transportation network of a country usually consists of several other modes besides rail, even though the modelling of rail is a more challenging task. All the existing modes such as road, fluvial navigation, coastal navigation, etc. have to be represented in a complete network model.

In Brazil, the road mode plays a major role, as trucks transport a large proportion of freight, measured either in tonnage or value. The navigation modes are also used, as well as other means of carrying freight, such as pipelines and air. Intermodal transfer facilities and ports form an important component of the transportation network and must be present in the network model as special modes. In the project, we established the modeling principles for representing the road, port and navigation modes. A number of issues, that must be considered if other modes are to be included in the model, are discussed as well.

Even though the road mode is one of the most important in terms of quantities of goods shipped, its representation is relatively straightforward by using the standard components of the transportation network. For strategic planning purposes, most

of the links of the road mode are not subject to congestion, although volume/delay curves, which model congestion, may be specified for links which are near major urban agglomerations, where heavy traffic may prevail. The road mode is often used to transport freight to or from a rail terminal or a port, where the goods are transshipped between the road mode and other modes. In such cases, transfer nodes must be specified with the appropriate attributes. Even though the modeling of the road mode and its associated network is rather straightforward, the data collection necessary in order to properly classify the links of the network and to define the appropriate cost functions is not a trivial task, as it involves a large number of links with widely different characteristics.

Ports represent a major element of the national multimodal transportation system of Brazil, since there are a number of important ports on the Atlantic Ocean coast that are accessible by road, rail and navigation modes. Imports and exports usually flow through these ports, as well as domestic traffic that uses the coastal navigation system. Port facilities, capacities and operations have a significant impact upon the performance of the entire network and a strategic model must capture these effects.

After a detailed analysis of port operations was carried out, that identified the operational components such as acces to port, movement and delay in vehicle, vehicle loading/unloading, storage, direct loading/unloading, etc..., a representation of a port was devised that consists of a small network that uses nodes, links and intermodal transfers, with associated cost functions. This representation is a simplification of the temporal activities that occur in a port, since the strategic multimode multiproduct transportation model is a static formulation. The specification of the delay, cost and fuel consumption functions for the port networks requires care, as the calibration of these functions is a rather delicate procedure.

The navigation modes are important for Brazil, as ocean navigation, linking ports in Brazil to ports in other countries, coastal navigation for freight movements along the coast between domestic ports, and internal navigation in the rivers and lakes, are present. The navigation network consists of the same elements as the rest of the transportation network, and are consistent with the restriction imposed by the strategic level of representation and analysis. A general model of the navigation modes was developed, that respects these requirements and that may be adapted for all types of navigation.

The general modeling principles used for the representation of the rail, road, port and navigation modes are equally valid for the modeling of any other transportation mode, with the restrictions imposed by a strategic modeling framework. Also, it is important to represent the mode in a uniform way, that is consistent with all the other modes included in a particular scenario.

The modeling of the road, ports, navigation modes and other modes is the subject of Part 2, Chapter V of this report.

Another methodological contribution, which was not fully exploited during the project, is a method based on an Augmented Lagrangean approach, to compute maximal multicommodity flows on a multimodal network. The purpose of such a method is to analyse and identify the capacity "bottleneck" of a freight transportation network. This topic is the subject of Part 2, Chapter VI of this report.

In rail transportation, the train travel between two consecutive stations depends on the distance travelled, the average speed of the train, the physical characteristics of the rail line and the number of trains that pass on the line during a given time period. In order to model this travel time, it was necessary to adapt formulae that are used at the operational level to determine the average travel line on a rail segment, to

determine the delay characteristics of travel by the rail mode for strategic planning model. By necessity, such formulae are more aggregate. Since in a strategic planning model the flows of products are measured in tons, it was necessary to develop formulae that convert the number of tons to an estimation of the total train traffic on a link and a polynomial approximation of the over-the-line delays. The procedures that were used to calibrate and validate these functions are presented in Part 2, Chapter VII of this report.

The final methodological contributions are the consideration of strict capacity constraints in the multimode multiproduct assignment procedure and a description of the numerical approximation procedure used to compute partial derivatives of the cost functions in the assignment procedure. These topics are described in Part 2, Chapters VIII and IX of this report.

3.3 THE STAN SYSTEM

One of the main achievements of the project is the development of STAN (**S**trategic **T**ransportation **AN**alysis), an interactive-graphic multiproduct multimode method for national or regional strategic planning of freight transportation. Although STAN is specifically designed for freight transportation, and is based on the methodological contributions made during the project, it was based to a large extent on the design of EMME/2, which is an interactive-graphic multimode method for urban and regional planning for the transportation of persons developed at the CRT-UdeM. In particular, the user interface is very similar to that used in EMME/2.

A typical use of STAN is the comparison and evaluation of alternatives. Usually, an existing situation is described by one of the scenarios of the data base. A simulation

of freight flows is carried out. Future situations are described by other scenarios which are constructed and contained in the data base. The simulation of freight flows is carried out on these scenarios as well. Then flows, link costs and delays, intermodal shipments and other performance indicators may be compared to those of the base scenario in order to carry out cost/benefit analyses and other economic evaluations.

STAN is among the first interactive-graphic methods designed for strategic planning of freight flows at the national level. It allows the planner to engage in the planning process by using terminology that he is familiar with and obviates data processing type tasks. It also permits him the instantaneous visualization of input data, results of computations and information retrieved from the data base, all in graphic or list form.

The installation of STAN at GEIPOT and PUC-RJ achieved one of the main objectives of the project, that of providing the means for a strategic planning capability which may be used on a continuous basis to analyse various issues of national importance.

Part 3 of this report gives an overview of the STAN system in Chapter I and a full description of the Basic System Concepts in Chapter II. STAN has also been used to compute and generate the figures that appear in this chapter.

3.4 SPECIFYING DATA FOR THE STAN SYSTEM

Much attention has been given during the design and development of the STAN system to the careful definition of the information requirements. It was decided early in the project that no new data will be collected and that all the data necessary for the project will be extracted from existing data sources. Thus, a considerable effort

was dedicated to the compilation of the available data sources and in reconciling and analysing the data that would be used for the envisaged applications in Brazil.

Ideally, the data necessary for constructing planning scenarios are determined in order to permit a policy sensitive representation and analysis of the system under study. In practice, one has to take into account the data available, the requirements of the modeling and algorithmic approach and also, the anticipated efficiency of the solution and evaluation methods of the available computer-based system. The collection of data is a multi-step process, that requires that choices be made at each step of developping the database for a particular application.

STAN requires data describing the components of the multi-modal transportation network (modes, nodes, links, transfers) and their attributes (vehicles, lengths, capacities, unit costs, associated functions, etc.) and data quantifying the transportation demand that is to be shipped, on the permitted modes, from each origin to destination.

The first step in the definition of the data base for a new application, is to divide the region under study into traffic zones, and to associate a centroid to each zone. Zones are generally divided according to several criteria, such as homogeneity, concordance with natural boundaries and compatibility with the main available data sources. For the Brazilian applications, we have adopted the zone definitions used by GEIPOT, which are sufficiently close to the zone subdivisions proposed by IBGE in order to permit the use of data originating from this important source.

The zones defined by GEIPOT served to subdivide the South-East region, while outside the region several groups of zones have been aggregated into, so-called, *External Zones.* To specify the External Zones, the GEIPOT zones that have significant trade flows with the South-East region were retained. The other zones were

Figure 1 External Zone Connections

subsequently aggregated into appropriate groupings. Figure 1 illustrates the main connextions between the study area and these External Zones.

The network for the South-East region application was defined by starting with a rather detailed network representation developed by GEIPOT. This network was subsequently aggregated, simplified and updated by using various data sources: DNER for the road; RFFSA, FEPASA and CVRD for the rail network; PORTOBRAS for ports and SUNAMAN for the navigation mode. A list of the data sources used during the project is given at the end of Part 4 of this report. Figure 2 displays the resulting network representation of the multimodal transportation system of the region of the

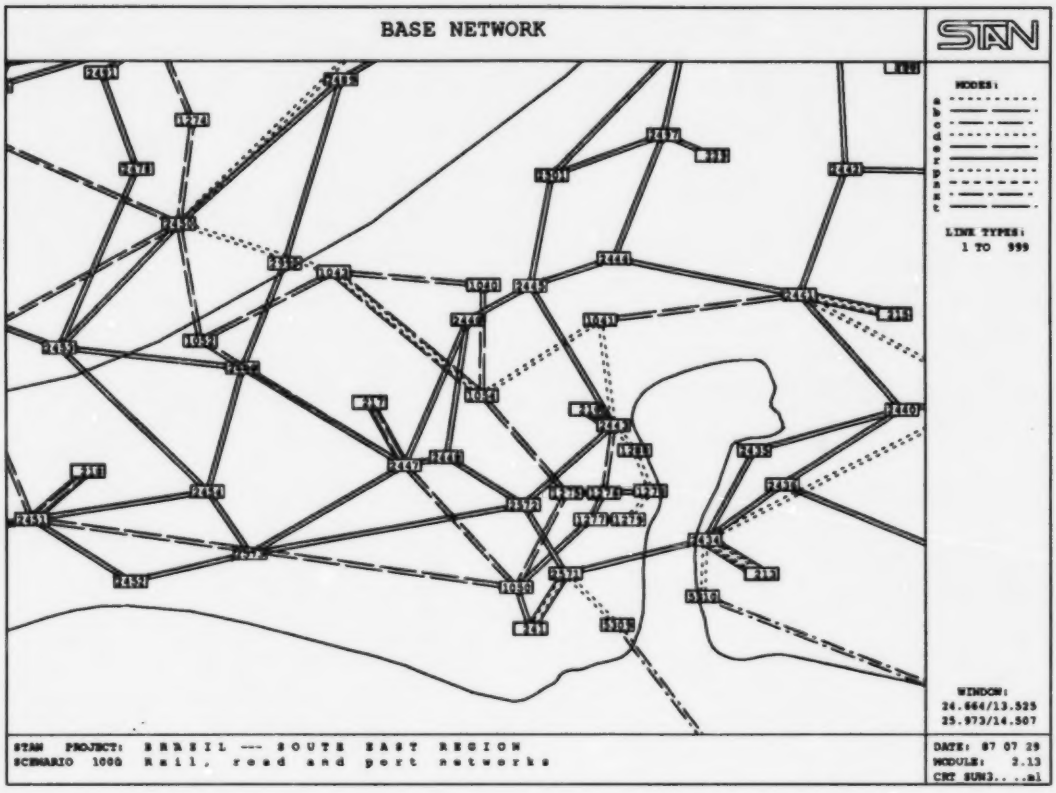

Figure 2 Multimodal Network

city of Rio de Janeiro.

In order to complete the specification of the transport services provided on this network, a variety of attributes had to be defined. These include the characteristics of the typical vehicles that transport each product on each mode, the physical characteristics and the functional forms for the transportation delay, costs and energy consumption for each link and transfer of the network. Figure 3 shows the behavior of a typical rail link delay function for various capacity figures and congestion levels. This exercise required long, arduous and often frustating efforts, often due to the lack of homogeneity among the data sources and sometimes due to lack of data.

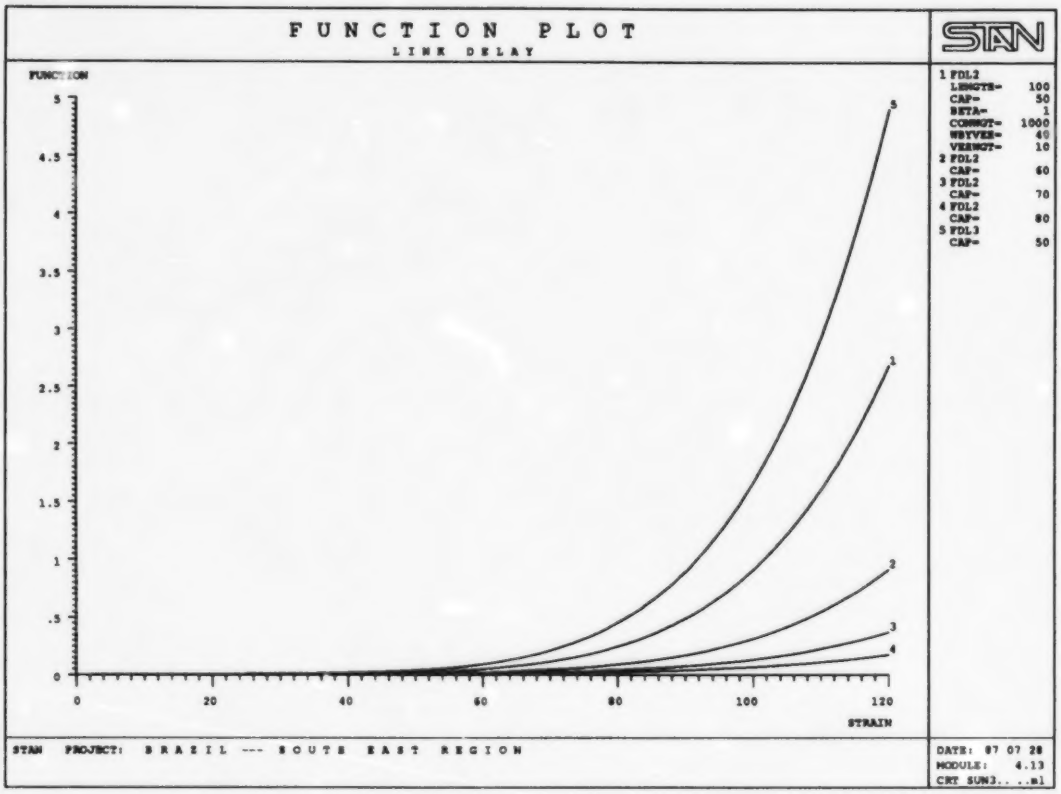

Figure 3 Rail Link Delay Functions

Data that permits a meaningful visual representation of the network was also included, such as spatial coordinates for nodes, demarcation lines for the national and regional boundaries, as well as natural (rivers and mountains) or artificial (hydro-electric works) geographical features. Demarcation lines constitute a raliant feature of most of the figures of this chapter, mainly Figure 1 and 9.

Building the origin-destination (O/D) matrices, containing the demand (in tons) of each product that was included in the study, could not have been successfully accomplished, within the time and budget resources of the project, without the help of existing data. In this respect, we were fortunate to have access to the O/D matri-

ces that had already been estimated by GEIPOT. These matrices were updated or aggregated according to the network definition of the South-East region application. For the purpose of the pilot phase of the project, only 8 of the 29 products, defined in the studies done by GEIPOT, were chosen for validation purposes. These products were chosen for their importance and impact on the transportation system in the South-East region and are: iron ore, steel products, coal, cement, fertilizers, soya oil, soya grain and soya meal. These products generate the major flows on the links of all the modes present in the region. Figure 4 shows the demand for transportation, for selected products, between a few of the External Zones and the region around the city of Rio de Janeiro. On the other hand, Figure 5 displays, for the same products, the total supplys and demands for the zones of the South-East Region.

For each product, either on exogenous mode choice is specified, or the assignment is performed on the multimodal network according to a chosen measure of generalized cost.

The issue of validating the origin/destination matrices by using information about the input/output structure of the economy of the region was examined briefly as well.

In summary, a considerable amount of effort was dedicated to the compilation of the data sources available, and to the reconciliation and analysis of some of this data, with the dual purpose of validation and definition of a "base year" scenario and the definition of future scenarios. The experience acquired in building the data base was very valuable, and if STAN is to be used continually for strategic freight planning in Brazil, the base year data should be regularly updated.

A data base updating procedure requires the establishment of procedures which are exogenous to the STAN system. The issue was discussed during the project, but

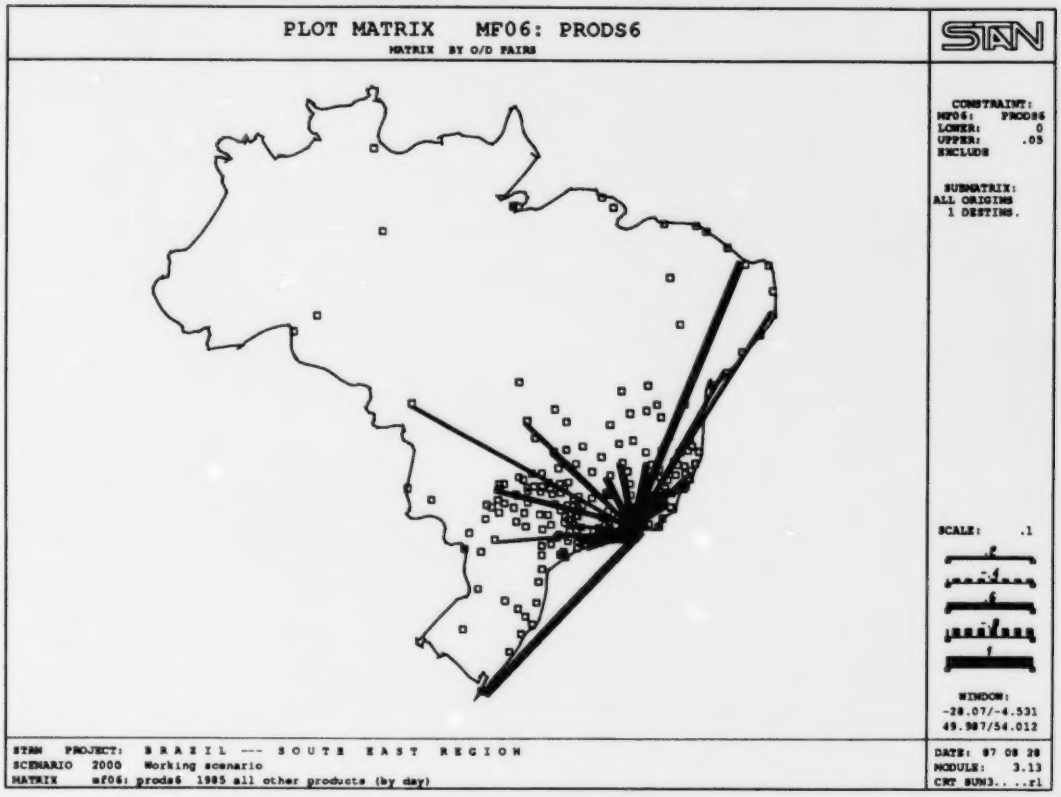

Figure 4 O/D Desire Lines

no definitive action was taken. We feel however that updating the data base is an important issue.

It may be worthwhile to emphasize the distinction between updating the data base and defining a scenario. The first activity aims to keep the information used in the data bank to reflect the actual state of the transportation system as close as possible to the reality. A scenario describes a hypothetical situation that one desires to evaluate and compare with the actual state of the system as present in the data bank.

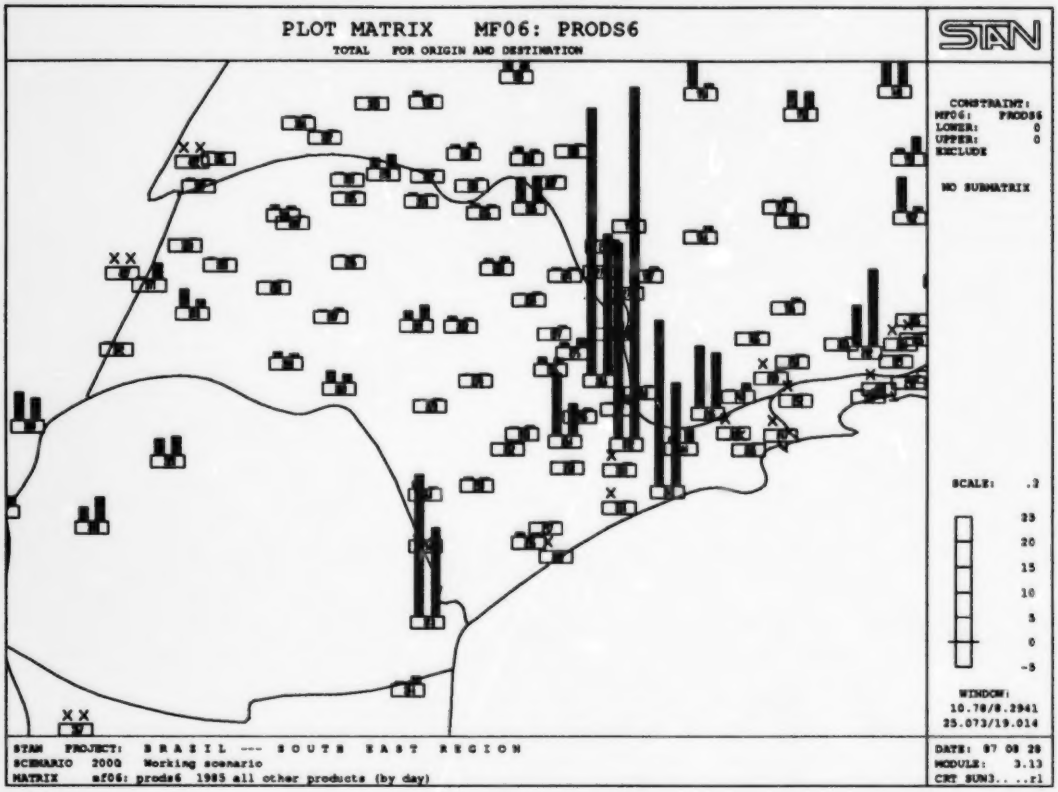

Figure 5 Zone Supplies and Demands

All elements of the transportation system may evolve in time: the multimodal network and its attributes, the operating policies and various costs of the diverse agents operating in the system, the demand for transportation. To reflect these modifications into the data bank, several data sources have to be used. Also, the required effort may significantly vary according to the type of data. A systematic procedure that gathers the necessary information from the different data sources and periodically channels this information for updating the STAN data base is a desirable future development.

Part 4 of this report describes in detail the collection and reconciliation of data for

the rail network (Chapter II), the highway mode (Chapter III), ports and navigation (Chapter IV) and transportation demand (Chapter V) for the South-East region data base.

3.5. THE APPLICATIONS

The ultimate goal of our project was the use of STAN for the strategic planning of freight transportation in Brazil. In order to meet this objective, it became essential to identify the Brazilian policies and alternatives for freight transportation, and the organizations responsible for their conception and implementation.

The strategic planning analyses of the transportation sector of Brazil were defined in accordance with the following national goals:

- To improve the stability of prices and to reduce the inflationary process;
- To equilibrate the balance of payments and to generate trade balance surplus, in order to reduce foreign debt;
- To resume the growth process, in order to overcome the recession problems due to idle production capacity and unemployment.

Clearly, these general goals have to be translated into specific projects and actions related to the transportation sector. The inflationary process motivated the need to identify policies that would improve the productivity of the transportation sector. The scarcity of resources indicated the need for a careful choice of investment projects and improvements in the operation of the system. The trade balance problem, due in large part to the foreign debt resulting from the petroleum crisis, led to an increase in exports and to a selective choice of imports, in order to increase

Brazil's capacity of repaying the debt. The transportation sector, which determines in part the competitiveness of the final prices for the exported and imported products, sought to select the best routes to use and to improve the productivity of the facilities through which these products moved.

The improvement of the transportation system was also considered as a factor in inducing economic growth in several areas. The Brazilian industrial sector is becoming more and more diversified, complex and interdependent. Also, the agricultural and cattle-raising sector is expanding is frontiers. Therefore, the need for adapting the transportation system to the requirements of the domestic and foreign markets is mandatory for the achievment of economic expansion.

In addition, the expansion of transportation services leads to increased demand for energy consumption, most of which is imported in Brazil. The national energy policy means to control and reduce fuel consumption in the transportation sector are the assignment of products to fuel efficient modes, the fleet modification and the utilization of alternative fuels.

In this context, different study areas were identified during the development of the STAN system and later on during the implementation phase, in order to concord with the needs and priorities of the Ministry of Transportation.

As mentioned earlier, the South-East region of Brazil was selected as the study area for the first application of the STAN system, to be used during its development phase, for the development of the methodological and modeling aspects, for the definition of the information to be included in the data base and for testing and validation. Several freight transportation scenarios were analysed by using this data base.

Figure 6 and 7 illustrate two types of results obtained during these analyses: the

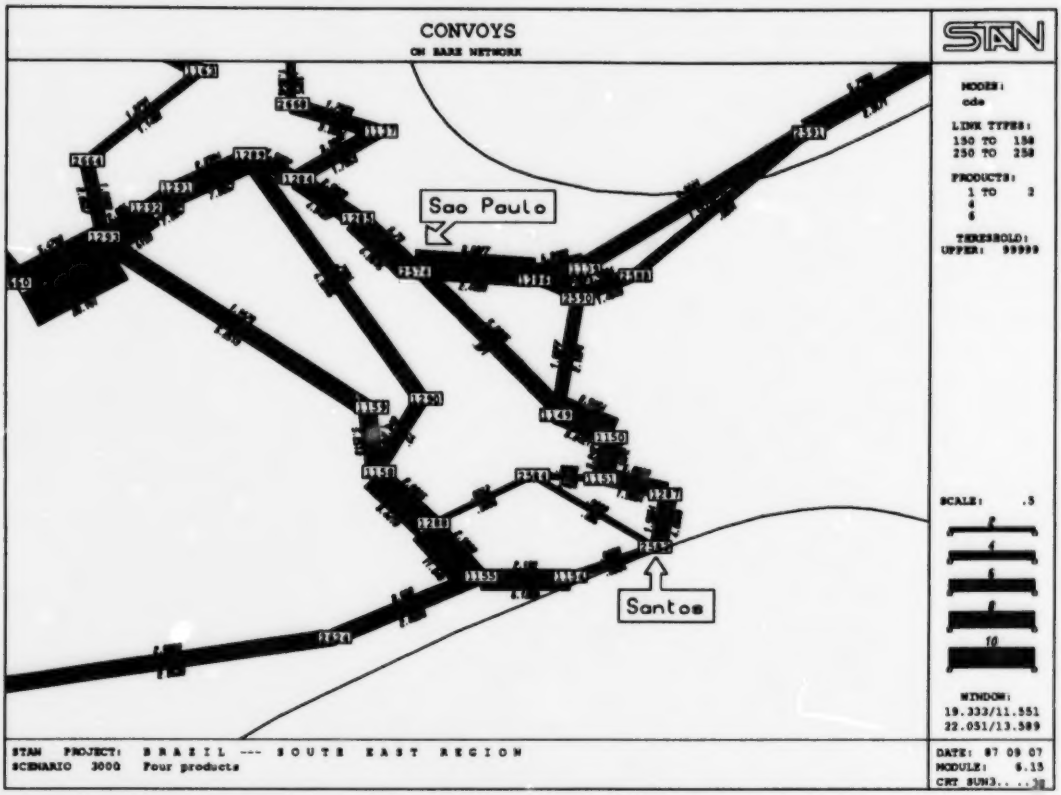

Figure 6 Convoy Flows

total (train) traffic in a given region and the multimodal shortest paths, according to the unit costs, from a specified zone to the others.

During the implementation phase of the project, that started after the installation of STAN at GEIPOT, several other applications were carried out in support of ongoing GEIPOT projects and one major application was carried out that fits within the Strategic Corridors Program of the Ministry of Transportation of Brazil. The application to the South-East region was continued, during this phase, principally concerning the conceptual and pratical definition of the data required and the information sources available.

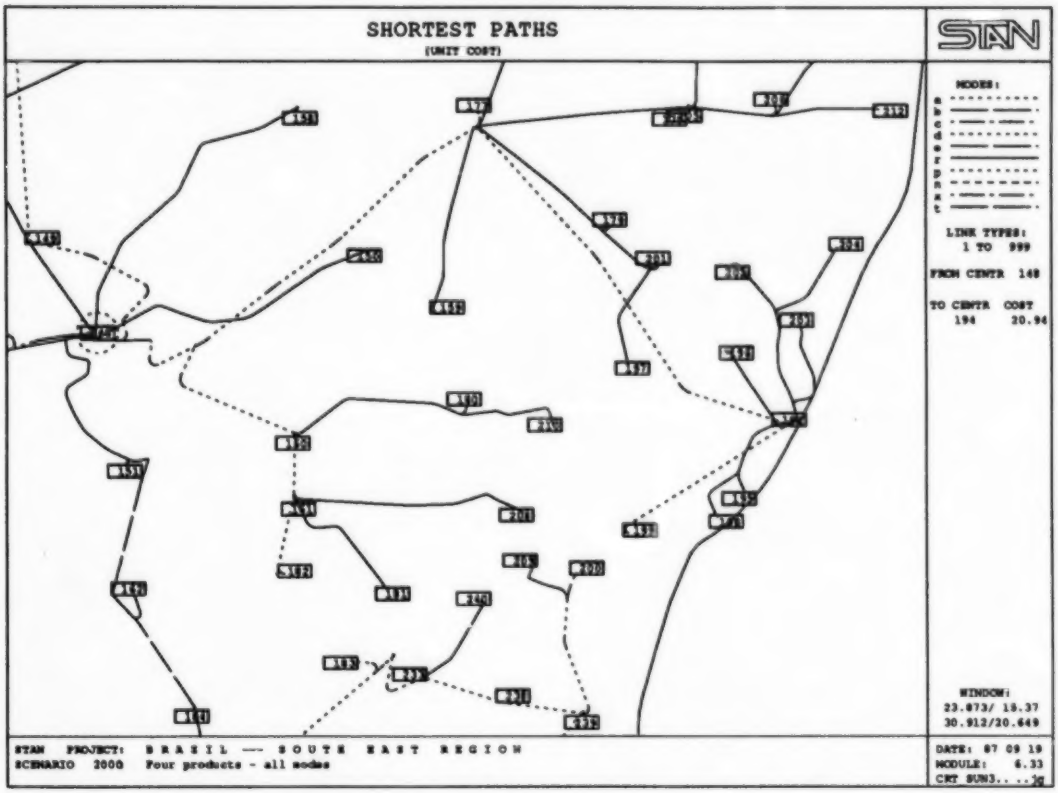

Figure 7 Unit Cost Shortest Paths

A Strategic Corridor consists of a set of facilities, along certain transportation axes, which have the aim of expanding the economic frontier of Brazil. More precisely, this concept includes all the transportation means (all modes), storage facilities and intra and intersectorial interfaces. Such a transportation structure may be viewed as starting at the coast and gradually penetrating the interior. The Strategic Corridors Program included two types of projects: basic studies, to evaluate the effects of cargo flows generated by the development of new economic frontiers and studies for making the corridors operational, by considering new investments in infrastructure for the transportation of the newly generated cargo flows. The Strategic Corridors are described in detail in Part 5, Chapter II of this report. Figure 8 shows the

geopolitical map of Brazil with the superposition of Export and Supply Corridors and of the Strategic Corridors.

During the implementation phase of the project, a complete study was carried out, by using the STAN system, on the São Francisco River Corridor. In the Strategic Corridors Program, the São Francisco river constitutes an important axis for the transportation system, that fulfills the goal of integrating new economic production areas with the national economy and serves as an alternate connection between the North-East and Center-South regions of Brazil. It corresponds to the valley of the river so named and is situated in the North-East of Brazil, covering parts of the States of Minas Gerais, Bahia, Pernambuco, Cíara and Piaui. Presently, it is a sparsely populated and economically underdeveloped area; however it has good development prospects for the next decades due to several public and private initiatives, mainly in the agricultural and transformation activities (irrigation programs, building of sugarcane distilleries for alcohol production, etc.). It is anticipated that the new developments will result in a significant increase in the demand for transportation inside the region of the corridor, which will add to the traffic between the South-East and the North/North-East regions of Brazil that use the transportation system of the corridor.

The study aimed to examine the distribution of the flows and the utilization of the transportation system, given the projected increase of demand and, in particular, to study the impact of two major investment efforts: the first aimed at improving the navigation on the São Francisco river, while the second is the construction of a new rail link. Several scenarios have been defined and analysed. No investments were planned in the highway network, nor in the rest of the regional network.

Five products were selected for the study: agricultural solid bulks (including soya

BASE NETWORK
STAN
I = RIO GRANDE DO SUL
II = SANTA CATARINA
III = PARANA
IV = SÃO PAULO
V = RIO DE JANEIRO
VI = MINAS GERAIS / ESPERITO SANTO
VII = CERRADO
VIII= NORDESTE 3 (SALVADOR)
IX = NORDESTE 2 (RECIFE)
X = NORDESTE 1 (FORTALEZA)
XI = RIO SÃO FRANCISCO
XII = ARAGUAIA - TOCANTINS
XIII= CUIABA - SANTAREM
XIV = FRONTEIRA NORDESTE
XV = AMAZONIA
CORRIDOR BOUNDARY
STATE BOUNDARY
MAIN RIVERS
STAN PROJECT: BRAZIL DATA BASE - GENERAL (PRODES7)
SCENARIO 1000 EXPORT AND SUPPLY CORRIDORS - CONSOLIDATED AND STRATEGIC
DATE: 89 10 25
MODULE: 3.13

Figure 8 The Brazilian Corridors

beans, corn and rice), gypsum, salt, ciment and petroleum byproducts including alcohol. These products represent 80% of the total traffic in this corridor. The situation in 1987 was chosen as the base year and demand projections were made for the year 1990. Direct surveys and a number of complementary studies, previously performed by or for agencies of the Brazilian Ministry of Transportation, were used to estimate the 1987 origin/destination matrices and the 1990 total supply and demand for each product. Then, the 1990 origin/destination matrices were computed by using the matrix balancing procedures available in STAN. It is important to note, that in spite of the predicted economic development inside the corridor, the transit flows still represent 90% of the total demand, as illustrated in Figure 9 (the left and right bars

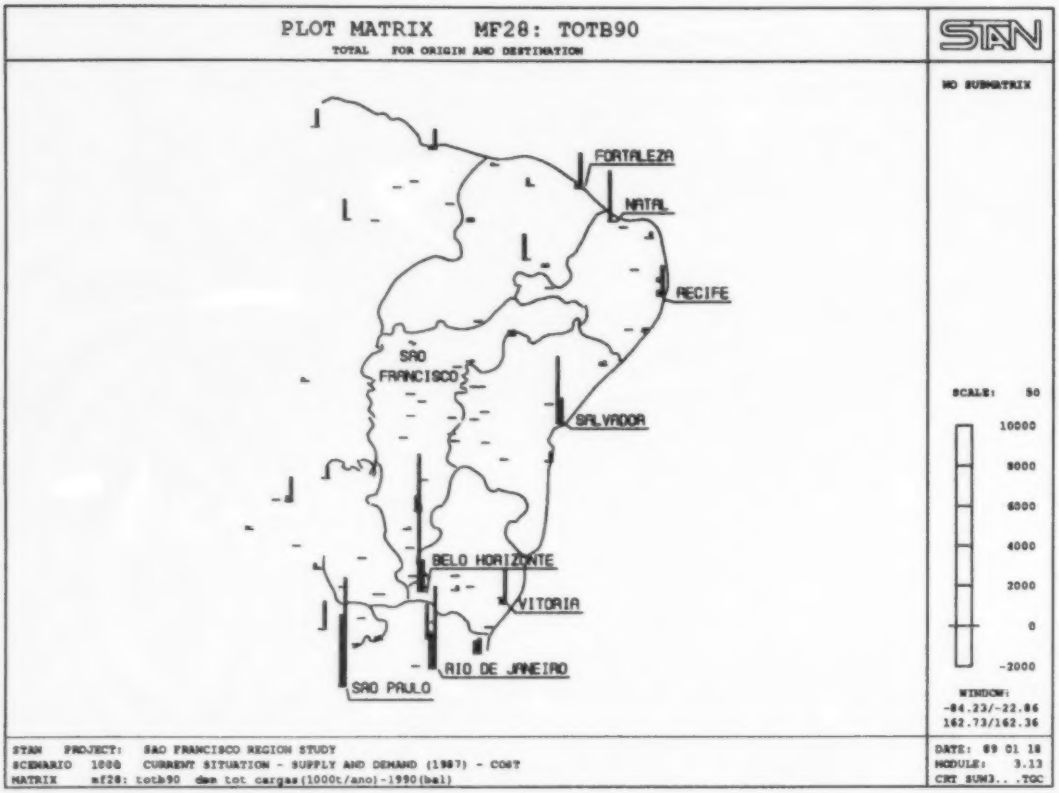

Figure 9 Total Supply and Demand Relevant to the São Francisco Corridor

represent the total supply and demand for the year 1990).

The current transportation network, see Figure 10, consists of a 1700 km long navigable section of the São Francisco River (mode h in our representation), 34,000 km of paved (mode p) and unpaved (mode t) roads, 13,400 km of metric gauge (mode e) and 1700 km of large gauge (mode l) railway, as well as 5000 km of coastal navigation (mode c). The necessary connectors and port links are also part of the infrastructure modeled. The STAN network has 76 centroids, 180 regular nodes, 856 links and 1672 transfers.

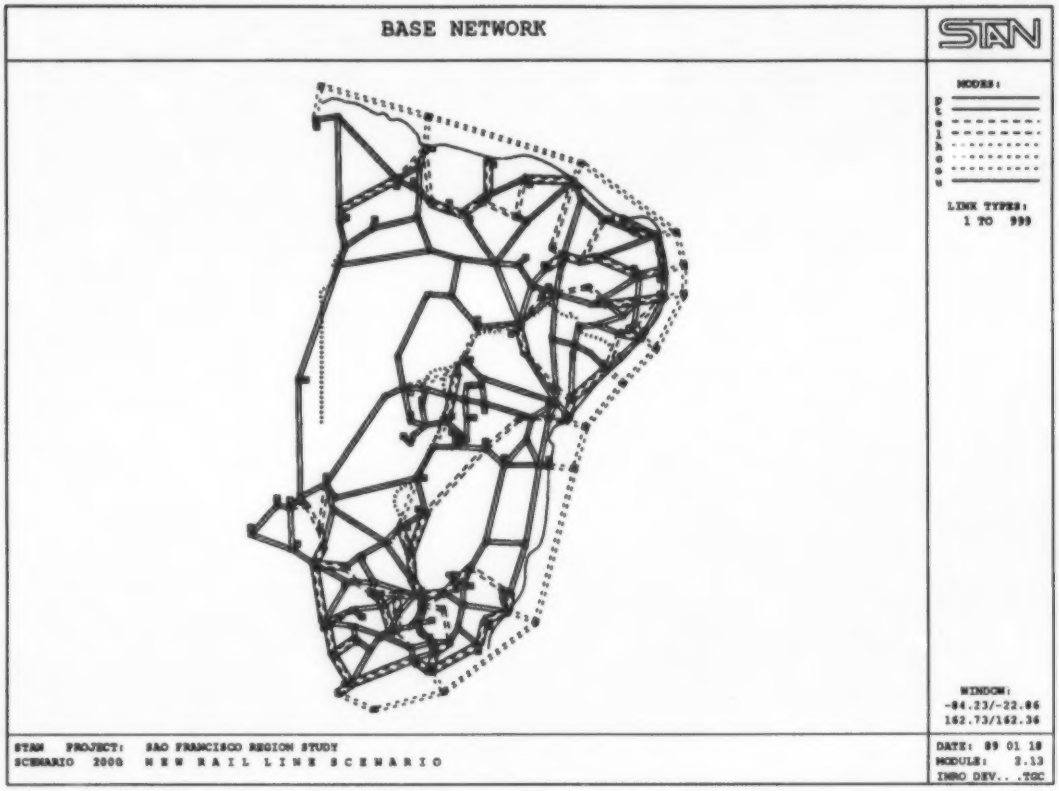

Figure 10 The São Francisco Corridor Current Transportation Network

The projected "Ferrovia Sertaneja", or "Transnordestina" Railway, see Figure 11, is aimed to achieve the goal of integrating the railway network in the Northeast of Brazil, significantly decreasing the rail distances in the region. In effect, the connection offered by the 450 km of the new line allows a direct rail link between the northern regions of Brazil and the other parts of the country. Intermodal transshipment facilities are planned to connect the road modes and the river navigation on the São Francisco. The new rail line will be constructed to concord with the technical characteristics of the regional rail network: single track, metric gauge, 30 km/h speed, 29 trains/day capacity.

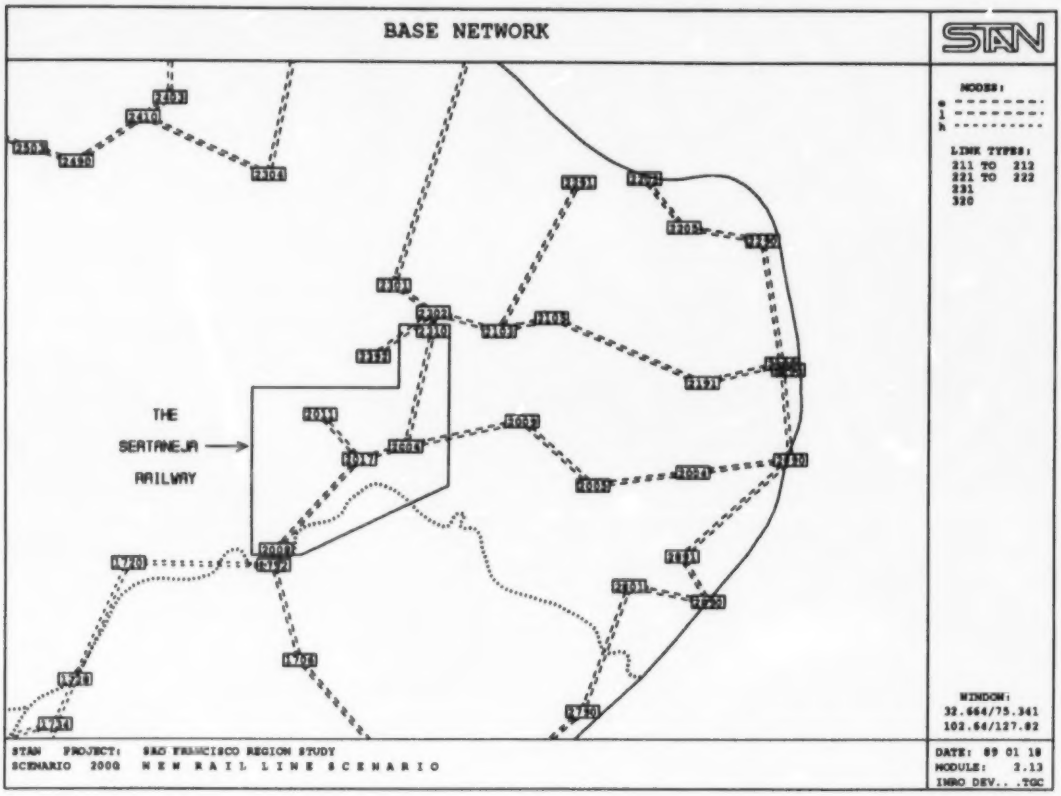

Figure 11 The Sertaneja Railway

The scenarios that have been analyzed, have been defined by modifying the permitted modes for the products and the flow assignment criterion. Due to the anticipated construction delays, only the projected demand matrix has been used with the transportation network which includes the new rail line. The planned improvements in the São Francisco waterway have been included in the study, by suitably modifying the cost and operational characteristics (service or transportation time, capacity, etc.) of the river ports and of the navigation lines.

The links of the road or navigation modes do not have explicit capacities. Port capacities were integrated into the linear functions used to estimate the total time

spent in port, while on the rail mode, link delays are computed by polynomial approximations.

By examining the results of the various scenarios, one notes that the "extreme" scenarios are performing as expected: with few negligible exceptions, when **time** is the assignment criterion, all traffic uses the road modes, while an assignment based solely on **cost** displays an almost exclusive use of the rail and navigation modes. The results of these two scenarios emphasize two points. First, even if the construction of the new rail line significantly decreases the rail travel time through the region, transportation by truck still offers the most rapid alternative, due to its higher speed and easier accessibility; second, the proposed capacity of the new rail line is sufficient for the anticipated traffic. In fact, the maximum expected traffic represents only about 10% of the planned capacity, which insures that there is enough spare capacity to accomodate the increases in traffic volumes, due to the expected continued expansion of the economic frontier.

The impact of the construction of the Sertaneja Railway on the utilization of the transportation system of the corridor, is most clearly appreciated by comparing the flows through the network with and without the new line. This comparison is illustrated in Figure 12 where, for clarity reasons, only the navigation and rail modes are shown. One notes a significant increase of the rail traffic and a heavy utilization of the new line, accompanied by a corresponding decrease in the transportation of the selected products by coastal navigation. This may be explained as follows. For the transit flows, the new rail line offers a direct route for the traffic between the northern and southern regions of Brazil, which is more convenient than coastal navigation, since, among other reasons, it avoids the use of ports; these contribute significantly to the travel time and cost. A similar reasoning applies to flows originating within or destined to zones of the corridor.

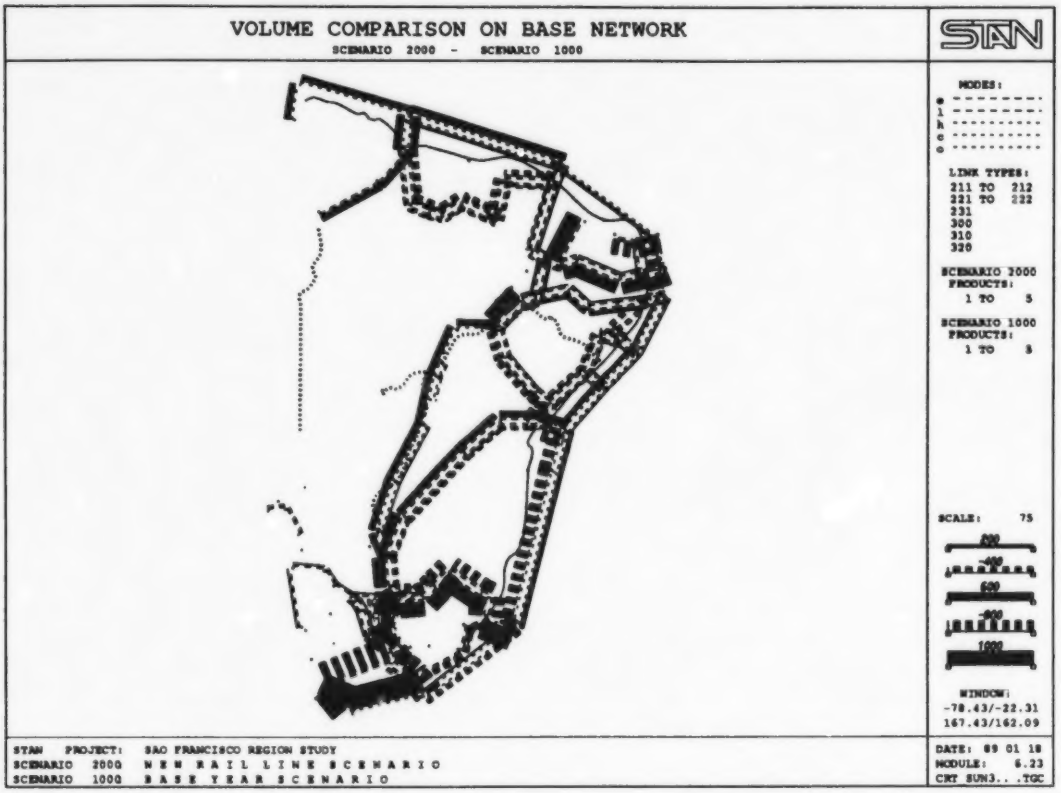

Figure 12 Traffic Distribution Comparison

In conclusion, the construction of the new rail line, which achieves the integration of the rail network in the north-east of Brazil and thus offers a direct rail link to several important freight flows, results in more freight attracted to the rail mode, in a decrease of the total distances travelled and, consequently, in an estimated 10% reduction of the total transportation cost. Regional flows are also attracted to the rail mode, which results in an increased use of the São Francisco waterway and a more economical use of the rail lines linking the coast to the interior. On the other hand, coastal navigation decreases as a result of the construction of the Sertaneja Railway, while trucking is still offering the most attractive alternative when time and accessibility are the preponderant criteria.

The São Francisco River Corridor application is described in detail in Part 5, Chapter III of this report.

The STAN system proved to be an analysis tool of great use for the strategic planning of the Transportation Sector in Brazil. The application had a practical use, as it was integrated in the study that evaluated the feasibility of making this strategic corridor operational.

CONCLUSIONS

It is clear from the contents of the preceeding sections that the main objectives of the project were achieved, in spite of the technical and organizational challenges and its relatively long duration.

The achievements of the project are most satisfying, since they span the range from new contributions to the methodology of strategic planning of freight transportation at the national level, the development of the STAN interactive-graphic system, which is based on these methods, and the development of concepts and estimation procedures for constructing the necessary data bases, to the applications that were carried out with STAN for strategic planning in Brazil.

Two important aspects of the project are those of technology transfer and transfer of knowledge among the teams participating in the project. Each of these aspects merits elaboration.

In this project, the CRT-UdeM team provided the impetus for the methodological developments, in collaboration with the PUC-RJ team and with contributions from the GEIPOT team. Numerous seminars were held in Brazil, which had the purpose of imparting the new developments to all the participants in the project and in particular to the persons who were to use the STAN system. These seminars served the purpose of explaining and disseminating the new methodology and to instruct the eventual users of the STAN system on all its aspects. All the computer programs that were written specifically for the project were transmitted to PUC-RJ and GEIPOT, with the aim of showing how the new methods were translated into a usable computer based method. Finally, the installation of the STAN system at GEIPOT and PUC-RJ provided these institutions with an operational strategic planning method for freight transportation which could be used in studies by GEIPOT or applied research

by PUC-RJ.

On the other hand, the analysis and description of the Brazilian context of freight transportation, the policy issues involved in national freight transportation planning and the analysis of the data sources required to this end, which were carried out by PUC-RJ and GEIPOT, provided the CRT-UdeM team with a unique opportunity to learn and familiarize themselves with problems that are faced by a developping country, such as Brazil.

Finally, the applications that were carried out during the implementation phase of the project served to show, in an unequivocal way, that the contributions made by the three collaborating organizations served a useful and productive end.

The results of the project are not limited to the strategic planning of freight transportation in Brazil. The approach used is sufficiently general to be used in other developing countries. The STAN system and the experience acquired and documented in this report with its use are transferable to other planning organizations in other countries.

Last, but not least, a project of this nature poses significant coordination and management challenges. In order to carry out the project to a successful completion, it is necessary to maintain continuity in the personal exchanges between the participating teams, to establish a joint work program which is updated as required and adapted to changes of governmental policy which affect the project. The successful completion of the project required that perseverance and commitment be maintained throughout its duration.